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OI 6300 Å nightglow emission at Calcutta and its verification by Barbier's equation in terms of solar flare index

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Abstract : The purpose of this paper is to represent the empirical relations between the solar flare index (I_f) and ionospheric parameters for the descending phase of 21st solar cycle and to express Barbier's equation as a function of a single variable I_f for a comparison with observed data. Important results have been obtained from the critical analysis of the observation .

Keywords : Airglow, Barbier's equation.

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1. Introduction

The effect of solar parameters on the different airglow emission lines have been studied by different investigators throughout the world. In all these studies, the above intensity has been correlated with the relative sunspot numbers, solar flare numbers *etc*. Barbier [1] showed that OI 6300 Å line intensity can be represented as a function of two most important ionospheric parameters f_0F_2 and $h'F$ which has been verified by a large number of investigators. Again these two ionospheric parameters vary also with the variation in different solar parameters. Chattopadhyay [2] has shown that f_0F_2 bears a strong correlation with sunspot number. But these solar parameters are often said not to take into account the total energy of any flare event. Solar flare index is being widely used now-a-days and is believed to give the actual energy-index of a flare event. In a previous paper Chattopadhyay *et al* [3] has shown that OI 6300 Å line intensity varies periodically with Sawyer's solar flare index. Hence we have chosen seasonal variation of 6300 Å emission and have tried to interpret the variation through Barbier's equation in terms of I_f. Atac [4] mentioned that Sawyer-solar-flare index I_f can be calculated by the following formula;

$$I_f = 0.76 \Sigma A_d^2 \tag{1}$$

Here, A_d – flare area in millionth of solar disc,

T^* – effective observing time in minutes

In our previous papers [5–7], we have shown that the intensity of 5577 Å and 5893 Å lines vary periodically with different solar parameters, while another work of our group [8] presents the possible explanation of the covariation of oxygen 5577 Å and 6300 Å line emissions.

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So one may expect seasonal variation of 6300 Å line intensity to agree fairly well with that calculated from Barbier's equation in terms of solar flare index I_f.

2. Observation and method of analysis

Seasonal variation of 6300 Å line is given in our previous paper [8]. Detailed experimental arrangements are given elsewhere [9]. Observation of 6300 Å line intensity, noted by Dunn-Manring type photometer during the period 1984-1986, is used for analysis.

The monthly variation of $h'F$ and f_0F_2 with I_f for the years 1984-1986 are used to find the empirical relation between solar flare index and ionospheric parameters. Solar data are taken from Solar Geophysical Data published by NOAA, Department of Commerce, USA and in absence of ionospheric data of Kolkata, data of the observing station Ahmedabad are used for analysis. Station Ahmedabad is chosen because it is latitudinally very close to Kolkata and the features such as ionospheric content and dynamics are predominantly controlled by terrestrial magnetic influence and therefore, are essentially related to latitude only. Due to unavailability of ready I_f data for seven months, the empirical equation expressing I_f as a function of relative sunspot number only [10] has been used.

Observed values of relative sunspot number for the corresponding period have been put into the empirical equation (2) and the corresponding values of I_f have been found out.

$$I_f = 1.0932\ (\text{relative sunspot number}) - 9.4391 \qquad (2)$$

According to Takakura *et al* [11] most intensive centrimetric and metric burst tend to occur in the descending or ascending phase of solar cycle avoiding the peak phase. In this connection it may be mentioned that our period of airglow observation (1984-1986) is not the peak phase. It is the secondary peak of descending phase of 21st solar cycle.

The theoretical intensity Q of airglow emission is given by Barbier's equation [1]

$$Q = A + B(f_0F_2)^2 \exp[-(h'F - 200)/H] \qquad (3)$$

while Barbier-modified intensity term is given by

$$Q' = (Q - A)/B = (f_0F_2)^2 \exp[-(h'F - 200)/H] \qquad (4)$$

Here, A and B are constants, f_0F_2 is the critical frequency of F_2 layer in MHz and $h'F$ is the virtual height of F-layer and H is the scale height of oxygen both in km. The two empirical equations obtained from the best fit curves (Figures 1 and 2), (found using method of collocation and successive approximation) for the seasonal variation of $h'F$ and f_0F_2 with I_f for the period 1984-1986 respectively are given below :

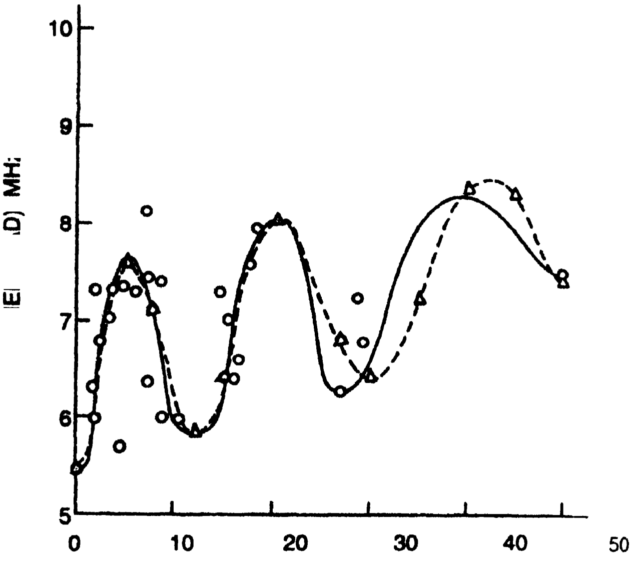

Figure 1. The scatter diagram between monthly mean values of I_f and f_0F_2 respectively along with best-fit curve for the years 1984-1986.

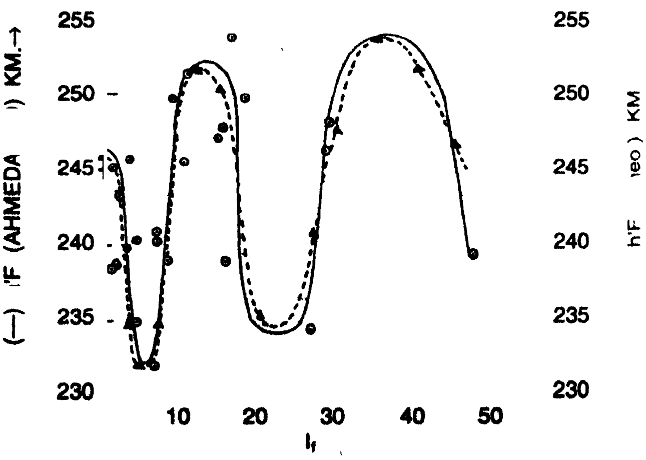

Figure 2. The scatter diagram between monthly mean values of I_f and $h'F$ respectively along with best-fit curve for the years 1984-1986.

$$h'F(\text{km}) = \{10 - 3.75 \times 10^{-3}(20 - I_f)^2\} + 237 \exp\{-10^{-5}(I_f - 55)^2\} + \{10.5 - 7.5 \times 10^{-3}(20 - I_f)^2\} \times \cos\left[\frac{360 I_f}{2.62 + 1.035\times10^{-3}(I_f + 86.87)^2}\right], \qquad (5)$$

$$f_0F_2\ (\text{MHz}) = 9.52 \times 10^{-3}(I_f + 55.042) + 6.65 \times \exp\{-5.094 \times 10^{-5}(I_f - 50)^2\} \times$$

$$(1.03 - 2.36 \times 10^{-3} I_f) \times \sin\left\{\frac{(I_f - 2)\times 360}{12.25 + 0.13125 I_f}\right\} \quad (6)$$

Now, putting different I_f values for different months of the years mentioned earlier into eqs. (5) and (6), corresponding values of f_0F_2 and $h'F$ are calculated and putting them into eq. (4), values of corresponding OI 6300 Å line intensity-index are found out. Now, these calculated values of Q'_{6300} as function of I_f and observed values of Q_{6300} for different months of the years 1984-1986, are plotted graphically and compared (Figures 3). Figure 4 12-monthly running mean values of $Q'_{6300}(I_f)$ as function of observed I_f value and of Q_{6300} and values of Kleczec-flare index, all corresponding to same months of 1984-1985, are graphically plotted against months (Figure 4). Kleczec-flare-index [4] is given by $Q = (i \times t)$ where 'i' is the important coefficient of the flare (NGDC publication) and 't' is the duration of the flare in minutes. Kleczec flare-index has been calculated from smoothed out bar diagram plot of flare-index value for the year concerned, for Northern hemisphere.

3. Results and discussion

Graphical plots of $h'F$ (km) and f_0F_2 (MHz), versus I_f for the period 1984-1986 in separate figures (Figures 1 and 2) reveal an oscillatory mode of variation the concept of which was prompted by our previous works [3,12,13]. Following the method we used in our previous works, regression equations for the best fit curves have been found out. The correlation coefficients and the standard errors are found to be approximately equal to 0.6 and 0.12 respectively for both f_0F_2 and $h'F$. In this way, empirical relations of I_f with each of two ionospheric parameters namely, virtual height and critical frequency have been established. First part of the equation gives the direct dependence with I_f which resembles the dependence of f_0F_2 on sunspot number found in our previous paper [3]. The second part which is exponential in nature, gives probably the ionospheric variation associated with wind speed distribution throughout the globe while the oscillatory part arrises probably due to the variation in ionospheric activities related to the magnetic field distribution through spinning motion of Earth. Similar explanation was given in our earlier work too [14].

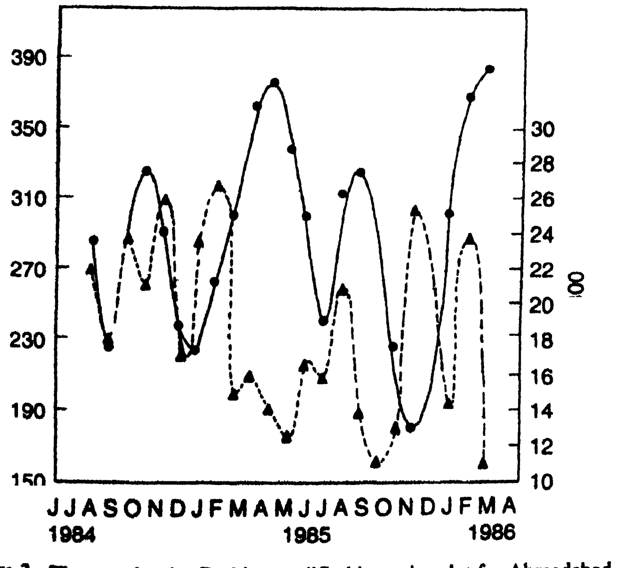

Figure 3. The month-wise Barbier modified intensity plot for Ahmedabad station for the years 1984 - 1986 along with the month-wise observed OI6300 Å line intensity plot for Narendrapur station for the years 1984-1986.

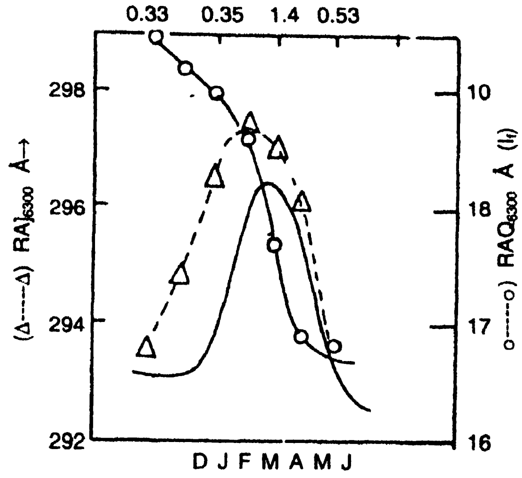

Figure 4. Running average values of Barbier modified intensity ($Q'_{6300}(I_f)$) and observed intensity (Q_{6300}) respectively are plotted simultaneously along with Kleczec-flare-index against month.

Then 12-monthly running average values of Q_{6300} (RA Q_{6300}) and Q'_{6300} (I_f) (RA Q'_{6300}) along with Kleczec-flare-index value, have been plotted in the same graph (Figure 4) in which it is observed that RA Q_{6300} bears a high positive correlation for second half with RA Q'_{6300} while a high negative correlation for the first half, respectively. But Kleczec-flare-index value directly plotted on the same graph, shows almost similar seasonal variation as that of RA Q_{6300}. Correlation coefficient for the whole portion of the graphical plot between RA Q_{6300} and RA Q'_{6300} has been found to be approximately –0.1 while for the second half portion of the same graph (Figure 4), has been calculated to be '0.79' with the standard error ≈0.2. Again correlation coefficient between RA Q_{6300} and Kleczec-flare-index for the same period as shown in Figure 4, has been found out to be '0.81' with standard error equals to 0.12 approximately. Due to scarcity of data, similar study could not be made for a very long period of time.

4. Conclusions

From the analysis and discussion made above, the following conclusions can be drawn;

(i) Theoretical values of 6300 Å nightglow intensity, calculated from modified Barbier's equation (4) using empirical relations (5,6) of ionospheric parameters h'F and f_0F_2 with Sawyer solar-flare index (I_f), show similar monthly variation as that of the observed values of OI 6300 Å for almost whole of the period 1984-1986. It is henceforth concluded that the empirical relations found out in this paper, can be used for comparison with any of the established models of ionosphere.

(ii) From the above-mentioned observation, it can also be concluded that Kleczec-flare-index is much more reliable than Sawyer's flare-index for investigations of covariation of ionospheric parameters and associated airglow intensity with solar-energy-flux parameter.

In addition to the total energy output and duration of flare-event, Kleczec-flare-index considers many other factors and all those factors are taken into a single implicit form known as importance (i). Sawyer's flare-index produces positive and negative correlations with ionospheric activities, simply because it does not consider other factors as in Kleczec-flare-index. Those extra factors probably have stronger influence on the terrestrial ionospheric activities.

(iii) The constants A and B in Barbier's equation are suspected [14] for not to be universal constants as both of them have dependence on various local and global ionospheric factors. In one of our papers [15], we have used Barbier's equation in terms of different solar parameters to calculate the intensity of oxygen green line 5577 Å and the result shows that calculated intensity does not agree well with the experimental values for a particular set of A and B values of the Barbier's equation.

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